Massachusetts
Department
Of
Public Health

Evaluation of the Incidence of the Ewing's Family of Tumors on Cape Cod, Massachusetts and the PAVE PAWS Radar Station

December 2007

Bureau of
Environmental Health,
Community Assessment
Program

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I. INTRODUCTION AND BACKGROUND

At the request of several concerned residents, the Community Assessment Program (CAP) of the Massachusetts Department of Public Health (MDPH), Bureau of Environmental Health conducted an evaluation of the incidence of the Ewing's Family of Tumors (EFOT) on Cape Cod (see Figure 1). EFOT is a broad term used to identify several classifications of disease codes. This evaluation was initiated due to the residents' concerns about a suspected increase in the incidence of this rare type of cancer. Written correspondence from one individual provided limited information on 13 individuals (in some instances, name, address and/or date of diagnosis information was not provided) reported to have a diagnosis included in the EFOT between 1995 and present.

Ewing's Sarcoma was first identified by Dr. James Ewing in 1921 when he observed that this type of bone tumor was different from the more common type of bone cancer known as osteosarcoma. Since his discovery, this tumor has also been observed in soft tissues. These soft tissue tumors are referred to as extraosseous (outside bone) Ewing (EOE). A third type of tumor shares many of the same features as Ewing's and EOE and it is called a peripheral primitive neuroectodermal tumor (pPNET). These three tumors make up the EFOT. Researchers have noted many similarities between the three tumor types: they have the same abnormalities in their DNA, they possess similar proteins that are rarely found in other cancer types, and they develop from the same type of cells within the body (ACS, 2007).

This investigation provides a review of the pattern of incidence of the EFOT on Cape Cod and compares it with the EFOT experience of the state of Massachusetts as a whole. Cancer incidence data for Cape Cod were obtained from the Massachusetts Cancer Registry (MCR) for the years 1995 to present. In addition to calculating cancer incidence rates, a qualitative analysis of the geographic distribution of individuals diagnosed with EFOT was conducted by mapping their residence at time of diagnosis. This was done to evaluate whether the geographic pattern of this cancer type on Cape Cod appears unusual. Similarly, the time of diagnosis was evaluated to determine whether a temporal pattern exists.

Emissions from the PAVE PAWS early warning radar system, which is located on the Massachusetts Military Reservation (MMR) in Barnstable County, was the primary environmental concern voiced by Cape residents who believed such emissions might be related in some way to the incidence of EFOT on the Cape. To address these concerns, MDPH worked with Broadcast Signal Labs (BSL), an engineering company, to take measurements of the radar facility's emissions in close proximity to the homes of individuals with EFOT or locations frequented by individuals with EFOT and in comparison areas. The MDPH legal department required BSL staff to sign a *Pledge of Confidentiality* in order to protect the confidentiality of these individuals. The results of BSL's work are included in Appendix A and discussed in this report.

II. METHODS FOR ANALYZING CANCER INCIDENCE

A. Case Definition

Due to the rarity of EFOT, MDPH contacted two pediatric oncologists from Boston, who specialize in childhood cancer, including EFOT, to assist the MDPH in the review of MCR data for individuals diagnosed with an EFOT.[1] As previously mentioned, the EFOT encompasses a heterogeneous group of tumors that include typical and atypical Ewing's sarcoma and pPNET, as well as some sarcomas of bone and soft tissue. From the medical literature, it appears that there is some disagreement among pathologists working in this area about the best way to define EFOT. For this investigation, after confirmation by the two pediatric oncologists, MDPH defined the EFOT using the following histology codes and primary sites:[2]

- 9260/3 (Ewing Sarcoma) - Not limited by primary site
- 9364/3 (Peripheral neuroectodermal tumor/pPNET) - all primary sites except C70.0-C72.9 (these include sites in the brain, meninges, spinal cord, cranial nerves, and other parts of the central nervous system)
- 9473/3 (Primitive neuroectodermal tumor, NOS) - all primary sites except

[1] To ensure the privacy of all patient information reviewed, MDPH's legal department required these physicians to sign a strict confidentiality agreement before reviewing any MCR data.
[2] Coding for cancer types in this report follows the International Classification of Diseases for Oncology (ICD-O) system 3rd Edition.

C70.0-C72.9 (these include sites in the brain, meninges, spinal cord, cranial nerves, and other parts of the central nervous system)

B. Case Identification

EFOT incidence data (i.e., reports of new cancer diagnoses) for Cape Cod for the years 1995-present were obtained from the MCR, a division of the MDPH Bureau of Health Information, Statistics, Research and Evaluation (BHISRE). The MCR is a population-based surveillance system that began collecting information in 1982 on Massachusetts residents diagnosed with cancer in the state. All newly diagnosed cancer cases among Massachusetts residents are required by law to be reported to the MCR within 6 months of the date of diagnosis (M.G.L. c.111 s.111B). [Note: MDPH is bound by state and federal patient privacy and research laws not to reveal the name or any other identifying information of an individual diagnosed with cancer and reported to the MCR.]

All diagnoses of EFOT reported to the MCR as primary cancers among residents of Cape Cod were included in the analysis. Individuals diagnosed with an EFOT were selected for inclusion based on the address reported to the hospital or reporting medical facility at the time of diagnosis.

As previously mentioned, information on 13 individuals reported to have a diagnosis of EFOT between 1995 and present was provided to the BEH by concerned residents. Of the 13 individuals reported to BEH, the CAP was able to confirm eight diagnoses using the MCR database. Two of the 13 individuals were diagnosed with a cancer type not within the EFOT. Two other individuals resided outside the study area (i.e., they did not reside on Cape Cod) at the time of their diagnosis. The remaining individual could not be confirmed because of insufficient information.

It should be noted that duplicate records have been eliminated from the MCR data used in this report. Duplicate cases are additional reports of the same primary site cancer diagnosed in an individual by another health-care provider. The decision that a case was a duplicate and should be excluded from the analyses was made by the MCR after consulting with the reporting hospital/diagnostic facility and obtaining additional information regarding the histology and/or pathology of the case. However, reports of individuals with multiple primary site cancers were included as separate cases in this report. In general, a diagnosis of a multiple primary cancer is defined by the MCR as a new cancer in a different location in the body or a new cancer of the same histology (cell type) as an earlier cancer, if diagnosed in the same primary site (original location in the body) more than 2 months after the initial diagnosis (MCR 2003).

C. Calculation of Standardized Incidence Ratios (SIRs)

To determine whether an elevation exists among individuals with a diagnosis included in the EFOT on Cape Cod, cancer incidence data were tabulated according to eighteen age groups to compare the observed number of cancer diagnoses to the number that would be expected based on the statewide cancer rate. Standardized incidence ratios (SIRs) were then calculated for the ten-year time period 1995-2004.

To calculate SIRs, it is necessary to obtain accurate population information. Typically, an estimate of the population between census years is calculated by assuming that the change in population occurs at a constant rate throughout the interval between each census.[3] However, because the mid-year for the 1995-2004 time period is 2000, a population estimate was not needed because 2000 is a census year.

D. Interpretation of a Standardized Incidence Ratio (SIR)

An SIR is an estimate of the occurrence of cancer in a population relative to what might be expected if the population had the same cancer experience as a larger comparison population designated as "normal" or average. Usually, the state as a whole is selected to be the comparison population. Using the state of Massachusetts as a comparison population provides a stable population base for the calculation of incidence rates.

Specifically, an SIR is the ratio of the observed number of cancer diagnoses in an area to the expected number of diagnoses multiplied by 100. The statewide age-specific incidence rates are applied to the population structure (i.e. age groupings) of each community to calculate the number of expected cancer diagnoses in the community.

[3] Using slightly different population estimates or statistical methodologies, such as grouping ages differently or rounding off numbers at different points during calculations, may produce results slightly different from those published in this report.

Comparison of SIRs between communities is not possible because each community has different population characteristics, specifically different age distributions.

An SIR of 100 indicates that the number of cancer diagnoses observed in the population being evaluated is equal to the number of cancer diagnoses expected, based on the comparison or "normal" population. An SIR greater than 100 indicates that more cancer diagnoses occurred than were expected, and an SIR less than 100 indicates that fewer cancer diagnoses occurred than were expected. Accordingly, an SIR of 150 is interpreted as 50% more cancer diagnoses than the expected number; an SIR of 90 indicates 10% fewer cancer diagnoses than expected.

Caution should be exercised, however, when interpreting an SIR. The interpretation of an SIR depends on both the size and the stability of the SIR. Two SIRs can have the same size but not the same stability. For example, an SIR of 150 based on four expected cases and six observed diagnoses indicates a 50% excess in cancer, but the excess is actually only two diagnoses. Conversely, an SIR of 150 based on 400 expected diagnoses and 600 observed diagnoses represents the same 50% excess in cancer, but because the SIR is based upon a greater number of diagnoses, the estimate is more stable. It is very unlikely that 200 excess diagnoses of cancer would occur by chance alone. As a result of the instability of incidence rates based on small numbers of diagnoses, SIRs are not calculated when fewer than five diagnoses are observed.

E. Calculation of the 95% Confidence Interval

To help interpret or measure the stability of an SIR, the statistical significance of each SIR was assessed by calculating a 95% confidence interval (95% CI) to determine if the observed number of diagnoses is “significantly different” from the expected number or if the difference may be due solely to chance (Rothman and Boice 1982). Specifically, a 95% CI is the range of estimated SIR values that have a 95% probability of including the true SIR for the population. If the 95% CI range does not include the value 100, then the study population is significantly different from the comparison or "normal" population. "Significantly different" means there is less than a 5% chance that the observed difference (either increase or decrease) is the result of random fluctuation in the number of observed cancer diagnoses.

For example, if a confidence interval does not include 100 and the interval is above 100 (e.g., 105–130), there is a statistically significant excess in the number of cancer diagnoses. Similarly, if the confidence interval does not include 100 and the interval is below 100 (e.g., 45–96), the number of cancer diagnoses is statistically significantly lower than expected. If the confidence interval range includes 100, the true SIR may be 100. In this case, it cannot be determined with certainty that the difference between the observed and expected number of diagnoses reflects a real cancer increase or decrease or is the result of chance. It is important to note that statistical significance does not necessarily imply public health significance. Determination of statistical significance is just one tool used to interpret SIRs.

In addition to the range of the estimates contained in the confidence interval, the width of the confidence interval also reflects the stability of the SIR estimate. For example, a narrow confidence interval, such as 103–115, allows a fair level of certainty that the calculated SIR is close to the true SIR for the population. A wide interval, for instance 85–450, leaves considerable doubt about the true SIR, which could be much lower than or much higher than the calculated SIR. This would indicate an unstable statistic. Again, due to the instability of incidence rates based on small numbers of diagnoses, statistical significance was not assessed when fewer than five diagnoses were observed.

F. Determination of Temporal and Geographic Distribution of Individuals Diagnosed with EFOT

In addition to calculating SIRs, year of diagnosis for each individual was reviewed to determine if a temporal pattern existed among individuals diagnosed with an EFOT on Cape Cod. Additionally, the address at the time of diagnosis for each individual diagnosed with an EFOT on Cape Cod was mapped using a computerized geographic information system (GIS) (ESRI 2006). This allowed assignment of location for each individual diagnosed with an EFOT as well as an evaluation of the spatial distribution of the individuals at a smaller geographic level within communities. The geographic pattern was assessed using a qualitative evaluation of the point pattern of cancer diagnoses on

Cape Cod. This evaluation also included consideration of the population density variability of each community through the use of GIS-generated population density overlays. In instances where the address information from the MCR was incomplete, that is, did not include specific streets or street numbers, efforts were made to research addresses for those individuals diagnosed with cancer (e.g., by using telephone books issued within 2 years of an individual's diagnosis or searching files via the Registry of Motor Vehicles database). For confidentiality reasons, it is not possible to include maps showing the locations of individuals diagnosed with cancer in this report.

III. RESULTS

A. EFOT Incidence

This section presents the EFOT incidence rates for Cape Cod during the 10-year time period 1995-2004 (see Table 1), the most recent period for which complete statewide data are available and hence for which SIRs can be calculated. Incidence rates have been calculated for children (0-19 years of age) and for children and adults combined (all ages). An SIR was not calculated for *adults only* due to the small number of observed cases (less than five). The observed numbers of diagnoses were compared to the numbers expected, based on statewide rates, to determine whether more EFOT diagnoses occurred on the Cape than would be expected.

One adult (i.e. an individual greater than 19 years of age) was diagnosed with an EFOT on Cape Cod between 1995 and 2004. Based on the demographics of Cape Cod approximately one individual would have been expected to have a diagnosis included in the EFOT.

From 1995-2004, more children on Cape Cod were diagnosed with an EFOT than expected. Seven children (ages 0-19) were diagnosed while approximately two would have been expected based on the statewide experience. This elevation is statistically significant (SIR=384, 95%CI =154-792). However, the width of the confidence interval shows that the SIR is unstable.

The incidence among children and adults combined was also above expected, eight individuals were diagnosed while three would have been expected. This elevation is statistically significant and is due primarily to the additional diagnoses observed among children.

At this time, the year 2004 is the latest year for which complete cancer incidence data are available statewide from the MCR. Because the MCR is a continual surveillance system, it is possible to review case reports for more recent years (2005 to the present). However, incidence rates can be calculated only through the year 2004. One additional diagnosis of an EFOT in a child has been reported to the MCR since 2005.

Age and gender patterns for the nine individuals diagnosed with the EFOT were reviewed. Five of the nine individuals are females while four are males. Ages at diagnosis ranged from two to 61 years of age with five of the nine individuals diagnosed within the second decade of life (i.e., 10-19 years of age).

B. Summary of Environmental Measurements Related to PAVE PAWS

BSL was originally commissioned to perform a study of emissions from PAVE PAWS, work that was overseen by the PAVE PAWS Public Health Steering Group (PPPHSG). The results of these findings were released in BSL's 2004 report entitled, *Final Test Report on A Survey of Radio Frequency Energy Field Emissions from the Cape Cod Air Force Station PAVE PAWS Radar Facility.* There were two objectives of this study. The first was to develop a model of the average radar emissions presented as a set of predicted values geographically represented on a map. The second objective was to measure average emissions and a maximum instantaneous peak emission from 50 sites on Cape Cod. BSL found that at all of the 50 PAVE PAWS test sites, "the radar's average power density was well below the Maximum Permissible Exposure (MPE)[4] specified by any known safety standard."

BSL's 2004 report, along with other studies related to PAVE PAWS, was critically evaluated by the National Research Council (NRC) in an independent review of potential health effects from exposure to PAVE PAWS emissions (NRC, 2005). (The NRC is part

[4] The MPE is the Institute of Electrical and Electronics Engineers' Std C95.1, 1999 Edition for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.

of the National Academy of Sciences.) In a briefing to the PPPHSG by the NRC, following its review, the NRC concluded that the available measurement data and models of the PAVE PAWS power density emissions provide a good first order characterization of the spatial distribution of the exposures occurring throughout the communities of Cape Cod (NRC, 2005a). Based on the available scientific evidence, the NRC also concluded that there are no adverse health effects to the population resulting from continuing or long-term exposure to the PAVE PAWS radiation. In spite of the measurements and estimates of the PAVE PAWS emissions, however, the NRC also concluded that there were no data for estimating personal exposure at the level of the individual (NRC, 2005a).

Following BSL's 2004 investigation, which focused on average emissions from the radar facility, some residents, particularly those concerned about the incidence of EFOT, voiced concern over the peak pulse power emitted from PAVE PAWS (i.e., peak power densities) at the household level. BSL's most recent work, in the vicinity of the homes of individuals' diagnosed with an EFOT, focused on the peak power densities from the radar station.

BSL conducted environmental measurements at 31 sites across Cape Cod to characterize the highest pulse peaks of radar arriving at each site from PAVE PAWS. The protocol for this testing was developed in collaboration with a resident of Cape Cod with engineering expertise as well as a personal interest in the EFOT.

Sites to be selected included residences of individuals diagnosed with EFOT as well as other sites (provided by the resident) that were locations where at least one individual diagnosed with EFOT spent a considerable amount of time. (As previously noted, each BSL employee who had access to confidential patient information (specifically, home address and no other personal/health information) was required by MDPH to sign a *Pledge of Confidentiality*). In order to assess whether these "index" sites might be unusual in terms of exposure opportunities from PAVE PAWS (i.e., higher levels of the peak power densities), the protocol also called for selecting comparison sites with similar characteristics important in assessing PAVE PAWS exposures (e.g., altitude and terrain that could block possible PAVE PAWS emissions) but where no individual diagnosed with EFOT resided or was known to frequent. If index and comparison site measurements were different (i.e., index sites were higher), this difference would warrant further exploration relative to its potential relationship to the occurrence of EFOT on Cape Cod. If the measurements were similar across all sites, this would suggest that PAVE PAWS emissions are not likely to play a primary role in the incidence of EFOT on Cape Cod.

The final number of sites selected and sampled was 31, 17 index and 14 comparison sites. As mentioned, BSL measured the pulse power peaks at each of these 31 locations. These measurements were taken to address concerns that earlier measurements taken by BSL in 2004 did not adequately account for peak pulses, which may play a more important role in possible health effects (BSL, 2004).

Data provided by BSL demonstrated that there is no difference between peak pulse emission measurements taken at index sites versus those taken at the comparison sites. Table 1 lists the maximum peak pulse power levels measured at each site, sorted from top to bottom in order from highest to lowest power.[5] The measured peak pulse power levels at the index sites were of magnitudes individually, and as a set, that were very similar to those measured at the comparison sites.

[5] The index and comparison sites are shown in the table side-by-side for ease of reading, not for evaluation purposes.

Table 1-Highest Peak Pulse Power Data

	Index Sites			Comparison Sites	
Value	Highest Measured Peak Pulse Power	Converted to Equivalent Power Density		Highest Measured Peak Pulse Power	Converted to Equivalent Power Density
Unit of Measure	dBm	dBμW/cm2		dBm	dBμW/cm2
Site no.			Site no.		
BSL04	-21	-12.8	PP09	-12.3	-4.1
BSL15	-31.6	-23.4	PP40	-13.1	-4.9
BSL05	-35.6	-27.4	PP16	-15.2	-7
BSL01	-36.6	-28.4	PP21	-21.6	-13.4
BSL03	-37.2	-29	PP19	-27.2	-19
BSL11	-41.8	-33.6	PP18	-31.6	-23.4
BSL07	-42.3	-34.1	PP17	-32.3	-24.1
BSL12	-49.9	-41.7	PP34	-43.5	-35.3
BSL17	-50	-41.8	PP07	-46.3	-38.1
BSL14	-53.1	-44.9	PP51	-47.9	-39.7
BSL02	-53.7	-45.5	PP50	-50	-41.8
BSL06	-54.1	-45.9	PP10	-52.8	-44.6
BSL10	-55	-46.8	PP42	-63.7	-55.5
BSL09	-59.6	-51.4	PP52	-68	-59.8
BSL08	-59.9	-51.7			
BSL13	-63.9	-55.7			
BSL16	-71.3	-63.1			

In Table 2, the results of the peak power measurements are summarized. The average level of peak pulse power is greater at the comparison sites than at the index sites. BSL also reported that the index sites do not have exceptional characteristics with respect to the general propagation of energy from the PAVE PAWS radar. The peak pulse power levels obtained at the index sites fall within the normal range of emissions expected from the PAVE PAWS radar at publicly accessible locations on Cape Cod. Thus, it appears that PAVE PAWS emissions alone do not explain the occurrence of EFOT on Cape Cod.

Table 2-Distributions of Highest Peak Pulse Power Measurements (dBm) of both Sets of Sites

Statistic	Index	Comparison
average	-48.04	-37.54
median	-50	-37.9
Std Dev	12.97	18.35
min	-71.3	-68
max	-21	-12.3

C. Geographic and Temporal Distribution of the EFOT Incidence on Cape Cod

In addition to determining incidence rates for the EFOT, a qualitative evaluation of the point pattern or spatial distribution of cancer diagnoses was conducted. Place of residence at the time of diagnosis was mapped for each individual diagnosed with an EFOT to assess the geographic distribution of the residences. The nine individuals lived in five of the fifteen communities on Cape Cod at the time of diagnosis, with Falmouth being the western-most community and Brewster being the eastern-most community (see Figure 1 for a map of towns on Cape Cod).

The majority of individuals lived at least one mile from each other at the time of their diagnosis. In one instance, two individuals lived in close proximity to one another at the time of their diagnosis (i.e., less than one-quarter mile); however, their diagnoses were approximately five years apart. The peak power densities measured in the vicinity of these two homes were similar, as would be expected given their close proximity; neither measurement was in the highest quartile of power density measurements for the index individuals. The geographic distribution of the majority of individuals diagnosed with an EFOT on Cape Cod closely followed the population density patterns of the communities. The greatest distance between any two individuals diagnosed with an EFOT was approximately 29 miles.

In addition, year of diagnosis for each individual was reviewed to determine if a temporal pattern existed among individuals diagnosed with an EFOT on Cape Cod. Two of the nine individuals diagnosed with an EFOT were diagnosed between 1995 and 2001. Six individuals were diagnosed between 2002 and 2004, with five of the six diagnoses occurring in 2003 and 2004. When examining peak power density values for these five individuals, none had power density measurements in the highest quartile of measurements for the index individuals. As previously mentioned, one individual has been diagnosed since 2005. Figure 2 shows the numbers of individuals diagnosed each year between 1995 and 2005.

D. Residential History

In general, many adult cancers have latency periods (i.e., the interval between first exposure to a disease-causing agent and the appearance of symptoms of the disease [Last, 1995]) that can range from 10 to 30 years and in some cases may be more than 40 or 50 years (Bang, 1996; Frumkin, 1995). While not much is known about the latency period for the EFOT, the length of time in which an individual lived in a specific area was considered to assess whether migration may have played a role in the incidence of EFOT. Therefore, a residential history of each individual diagnosed with an EFOT on Cape Cod was constructed from readily available information.

Residential histories were constructed by searching each town's annual street listings. Review of residential information indicated that six individuals lived at their reported address for at least five years prior to diagnosis, with the years of diagnosis ranging from 1996 to 2005. One individual, who was diagnosed in 2003, lived at their address at diagnosis for approximately two years prior to diagnosis and two individuals, one diagnosed in 2003 and the other in 2004, lived at their reported address for less than one year prior to diagnosis.

IV. DISCUSSION

According to the American Cancer Society, about 250 children and adolescents are diagnosed with the Ewing family of tumors in the United States each year (ACS 2007). According to a medical journal article on EFOT, the annual incidence of Ewing's sarcoma in the United States in white young people less than 21 years of age is two to three cases per million (Horowitz et al. 2006). Nationally, 2% to 3% of all childhood tumors are in the EFOT. Using national data available from the National Cancer Institute's Surveillance Epidemiology and End Results (SEER) program, MDPH computed both a national and statewide age-adjusted incidence rate for the EFOT for the 10-year period 1995-2004. (The statewide rate was based on MCR incidence data.) These rates include all ages and the same primary site and histology codes that form the basis of our case definition for this report (as recommended by MDPH's consulting pediatric oncologists). The U.S. and Massachusetts average annual age-adjusted incidence rates are similar: 2.2 and 2.3 diagnoses per million, respectively.

As with many pediatric tumors, slightly more males than females develop this cancer. Ewing's sarcoma is diagnosed during the second decade of life in 65 percent of patients. The Ewing's family of tumors can also affect adults into their 20s and 30s as well as children under 10. It is distinctly uncommon before age 5 and after age 30. About 15% occur in adults. Most of the patients are white, either non-Hispanic or Hispanic. This disease is very rare among African Americans, and it also seldom occurs in other racial or ethnic groups.

According to a National Cancer Institute monograph on childhood cancer, other than an important racial difference in incidence between black and white children (white children having an approximate 6-fold higher incidence rate than black children), no environmental factor or other characteristic has yet to be shown a strong risk factor for the EFOT (Ries et al. 1999). Genetic changes passed along with families are not an important risk factor for the EFOT and it is rare for more than one child in a family to develop EFOT (ACS 2007). The American Cancer Society reports that survivors of bilateral retinoblastoma (a genetic form of eye cancer) seem to have a higher incidence of EFOT. Researchers also have identified chromosomal changes that lead to EFOT (i.e., translocations involving chromosome number 22); however, researchers have found that these changes are not inherited.

The descriptive epidemiology, such as age and gender patterns as well as incidence patterns, of those diagnosed with the EFOT on Cape Cod appears to be somewhat different from what would be expected based on the epidemiological literature; however, some of these differences may be the result of comparing smaller numbers on Cape Cod to larger statewide or national databases. It is important to note that statistics and patterns related to the EFOT that are reported in the medical and epidemiological literature are based on national incidence data and are therefore much more stable and robust than those of the Cape, with a significantly smaller population. The EFOT accounted for 8.5% (7 out of 82) of all childhood cancer diagnoses on Cape Cod during the 10-year period evaluated compared to 2 to 3% nationwide (Ries et al. 1999). For the state of Massachusetts during the same 10-year period, 2% (61 out of 2,775) of all childhood cancers were in the EFOT. A difference of two or three diagnoses in the Cape population has a major effect on its statistics and cancer incidence patterns while this is not true for statewide or national statistics.

Slightly more females were diagnosed within the EFOT on Cape Cod while the epidemiological literature reports that slightly more males than females develop this type of cancer.

In considering the geographic distribution of residence at diagnosis of the nine individuals diagnosed with EFOT since 1995, with the exception of the two children who lived less than a quarter-mile apart at the time of their diagnosis, no spatial clustering of individuals was noted. Most of the individuals lived on either the Upper Cape or Mid Cape, with one individual being a resident of the Lower Cape at diagnosis. The spatial distribution of the residences closely followed the areas of greatest population density on the Upper and Mid Cape. Regarding the two children who lived within close proximity of one another, there was approximately a five-year span between their dates of diagnosis and, as mentioned, the peak power densities from PAVE PAWS measured at their homes were not in the highest quartile of power density measurements for the index sites.

Although the number of observed diagnoses of EFOT on the Cape was not statistically significantly different than the number expected, based on statewide incidence data, in considering the temporal distribution of the dates of diagnosis, the number of diagnoses during the years 2003 and 2004 in particular does seem unusual (total of five individuals diagnosed in these two years). Based on residential history information, it appears that one of the five individuals diagnosed during this two-year period became a full-time resident of Cape Cod in the same year as their diagnosis, and prior to being diagnosed, had a permanent residence in Massachusetts but not on Cape Cod. Another individual also lived at their residence for less than one year. Thus, it seems unlikely that these two individuals' diagnoses would be related to residency on Cape Cod. For the remaining three individuals, one lived at their residence of diagnosis for approximately two years while the other two individuals lived at their residence of diagnosis for at least five years. None of these five individuals had peak power density measurements in the highest quartile of measurements for the index sites.

MDPH sought assistance from two prominent pediatric oncologists in reviewing the incidence and case-specific data available from the MCR on the EFOT on Cape Cod. Both oncologists agreed that the temporal pattern does appear slightly unusual; that is, the number of diagnoses is slightly elevated during the years 2003 and 2004 in particular. However, based on their professional experience, they felt that if data on the EFOT were examined nationwide, other areas of the country may very well have similar 'spikes' in particular years. Further, the residential history of some of these individuals diagnosed during this time period suggests that residence on Cape Cod seems unlikely to be associated with their diagnoses. Nonetheless, MDPH and these two pediatric oncologists felt that monitoring the incidence of EFOT on Cape Cod to see if the temporal pattern persists over time was prudent.

MDPH also sought assistance from BSL to take additional environmental measurements of radar related to PAVE PAWS, to characterize the highest peak pulse emissions associated with the facility. Based on the findings of BSL's recent measurements, it appears that PAVE PAWS emissions are unlikely to have played a primary role in the occurrence of EFOT on Cape Cod.

V. CONCLUSIONS

- The incidence of Ewing's Family of Tumors (EFOT) on Cape Cod for the 10-year period of 1995-2004 was elevated in children (0 to 19 years of age). In children, seven diagnoses were reported to the MCR when approximately two would be expected.

- With one exception, no geographic or spatial clustering was noted when the place of residence at diagnosis was mapped for each individual diagnosed with a tumor in the Ewing's Family. Although two individuals lived in close proximity to one another at the time of their diagnosis, their diagnoses were approximately five years apart. Further, environmental measurements from PAVE PAWS at their homes were similar to one another, as would be expected due to their proximity, and were not in the highest quartile of power densities measured for index sites.
- Temporal clustering was noted in the years 2003 and 2004, with five individuals diagnosed with a tumor in the Ewing's Family in these two years. It is important to note that two of these individuals lived at their residences for less than one year making it less likely that residence on Cape Cod was associated with their diagnoses. Additionally, the peak power density measurements from PAVE PAWS for the five individuals were not in the highest quartile of measurements for the index sites.
- Environmental measurements related to the PAVE PAWS radar facility at the Massachusetts Military Reservation, taken at 31 locations across Cape Cod, showed that the measured peak pulse power levels at the index sites (locations in close proximity to the individuals diagnosed with an EFOT or locations frequented by the individuals) were very similar to those measured at comparison sites (locations similar in their relationship to PAVE PAWS as the index sites but not near the residences of individuals diagnosed with an EFOT).
- Based on this information it appears unlikely that PAVE PAWS played a primary role in the incidence of EFOT on Cape Cod.

VI. RECOMMENDATIONS

MDPH will continue to monitor the incidence of EFOT on Cape Cod and will work together with local health officials and community residents as appropriate.

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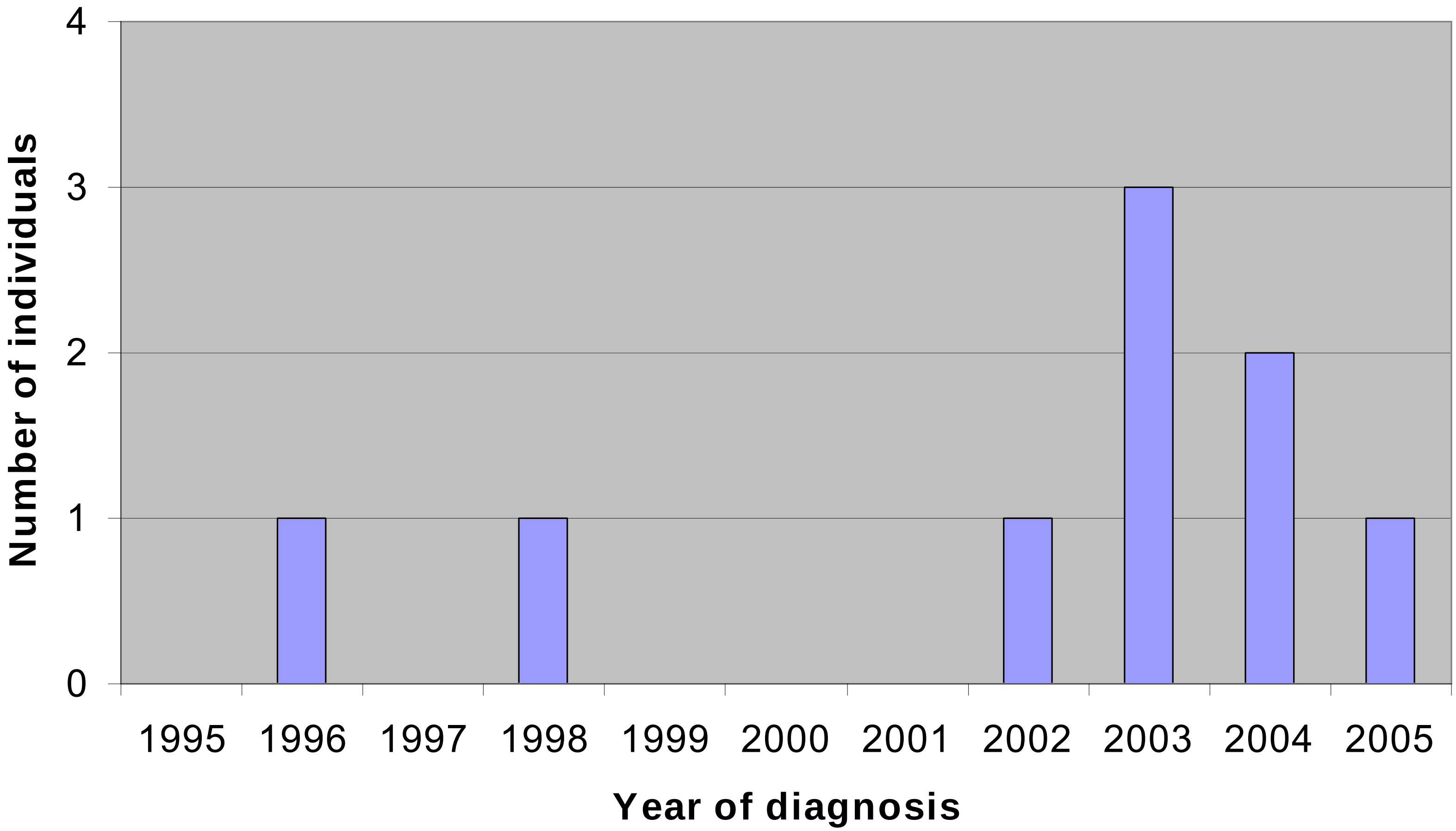
Figures

Figure 1
Cape Cod Communities

Figure 2

Number of diagnoses per year



Tables

TABLE 3
Ewing's Family of Tumors Incidence
Cape Cod, Massachusetts
1995-2004

	Total						
	Obs	**Exp**	**SIR**		**95% CI**		
ALL AGES	8	3	261	*	112	--	514
CHILDREN (0-19)	7	2	384	*	154	--	792
ADULTS (20+)	1	1	NC		NC	--	NC

Note: SIRs are calculated based on the exact number of expected cases.
Expected number of cases presented are rounded to the nearest tenth.
SIRs and 95% CI are not calculated when observed number of cases < 5.

Obs = Observed number of cases
Exp = Expected number of cases
SIR = Standardized Incidence Ratio
95% CI = 95% Confidence Interval
NC = Not calculated
* = Statistical significance

Data Source: Massachusetts Cancer Registry, Bureau of Health Information, Statistics, Research and Evaluation, Massachusetts Department of Public Health.

APPENDIX A

Broadcast Signal Lab's
Report on Pave Paws Peak Emissions Survey
For Massachusetts Department of Public Health

Broadcast Signal Lab

Report on Pave Paws Peak Emissions Survey
For Massachusetts Department of Public Health

October 2007

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Appendices

Figures and Tables

Additional figures and tables in appendices

Report on Pave Paws Peak Emissions Survey
For Massachusetts Department of Public Health

Introduction

Broadcast Signal Lab, LLP was funded by the Massachusetts Department of Public Health to evaluate the environmental emissions of the PAVE PAWS radar facility on the Massachusetts Military Reservation on Cape Cod. Broadcast Signal Lab performed an earlier study in 2004, commissioned by the PAVE PAWS Public Health Steering Group ("PPHSG"), funded by the US Air Force, and peer reviewed by the National Academy of Science. Following the 2004 study, additional questions were raised regarding the incidence of Ewing's Family of Tumors ("EFOT") on Cape Cod. The Department of Public Health sought to obtain more information on two aspects of the radar's environmental emissions.[6]

First, the 2004 study focused on developing a model of the environmental levels of average radar emissions presented as a set of predicted values geographically represented on a map of Cape Cod (map is shown in Appendix E). Field measurements were performed at that time to compare to the model. Minor attention was paid to the peak energy in the spectrum. The 2007 study was planned to examine the peak emissions more closely, and determining whether there may be a relationship between the new peak information and the 2004 average power density map.

Second, the 2004 study obtained average measurement data (and a maximum instantaneous peak sample) from 50 sites scattered across the Cape and on the mainland. A return visit to some of the 2004 sites to collect the peak pulse data would be done in tandem with measurements at newly selected sites in 2007.

Targeted in 2007 were locations, called "index" sites, that were directly or indirectly associated with individuals who developed EFOT. All measurements were made on public ways or property open to the public. These sites included locations in proximity to residences where individuals who were diagnosed between 1982 and the present lived and locations where some such individuals were known to frequent. Broadcast Signal Lab was directed to the index sites to

[6] As was the case in the 2004 study, we use the term "environmental emissions" here to refer to the energy emitted by the PAVE PAWS radar that reaches habitable and occupiable space on and near the ground. The studies do not consider the emissions that never reach the ground.

collect snapshots representative of the maximum radar peak pulse power arriving at each locus. These locations are kept confidential to protect the identity of individuals and are not specified in this report.

To provide a set of site data with which to compare the index site data, additional sites were selected and called “comparison” sites. Comparison sites were selected largely from the 2004 measurement sites to maintain a link between 2007 and 2004 results. They were selected to represent general geographic and signal level characteristics that are comparable to the characteristics of the index sites. Such characteristics included distance and bearing from the radar, terrain elevation, land cover (vegetation and structures), and signal path from radar (obstructed or line-of-sight).

In coordination with the Department of Public Health and a concerned resident, Broadcast Signal Lab developed a measurement protocol for this effort, which is contained in Appendix F. The 2007 peak analysis would be performed by collecting snapshots of the strongest radar pulses arriving at a location over a period of time. The methodology of this data collection process is described in detail in Appendix A. The mathematical basis for the measurements and computations is presented in Appendix B. Upon final approval of the protocol, Broadcast Signal Lab conducted field measurements of peak pulse power levels at a total of 31 sites, including index and comparison sites. Measurements were conducted between June 4 and 13, 2007.

The data were collected and combined in tabular form for processing. The twelve strongest peak snapshots for each site were identified and are presented in graphic form in Appendix C. The following narrative discusses at a summary level the data collected.

Sites

The measurement protocol in Appendix F discusses in substantial detail the nature of the emissions from the relevant faces of the radar and strategies for measuring it. In general, all sites were in essence “in front of” the radar—that is to say, the sites are at locations beneath the sweep of the radar, rather than “behind” the facility where it emits no beams. The radar’s primary mission is to sweep two-thirds of the sky, approximately 3 degrees above the horizon, to search for incoming objects (missiles, spacecraft, etc.).

The key physical characteristics of the two sets of sites, index and comparison, are compared in Table 1. Table 1 establishes the similarity of the two sets. The average predicted power densities at the index and comparison sites are quite close in distribution, with similar average, median and standard deviation values. The distributions of the average power densities, distances, and elevations of the index and comparison site sets are very close, as seen by comparing the standard deviations of each pair of attributes in Table 1. This provides reassurance that the index and comparison site sets are both representative of the variety of terrain, radar orientation, elevation, and distance factors available on upper Cape Cod. The average elevations are somewhat greater for the comparison sites versus the index sites, while the index sites tend to have a moderately greater distance. These differences are not significant. Because signals diminish greatly with lower elevation, assuming lower elevations tend to have more terrain blockage, and with distance, one may anticipate that if there is any difference observed between the comparison data and the index data, it could be that the typical peak power levels at the comparison sites would be slightly greater than for the set of index sites.

Table 1
Attributes of 17 Index and 14 Comparison Sites

	Average Power Density, dBμW/cm^2		Elevation, m		Distance, km	
Statistic	Index	Comparison	Index	Comparison	Index	Comparison
	Predicted	*Measured*				
average	-49.35	-44.46	25.41	32.36	18.18	14.70
median	-44	-45.50	26	35.82	15	8.98
Std Dev	16.62	15.08	19.55	21.43	12.16	12.05
min	-85	-66.50	0	3.96	>3	1.53
max	-23	-24.00	<60	76.83	<40	38.06

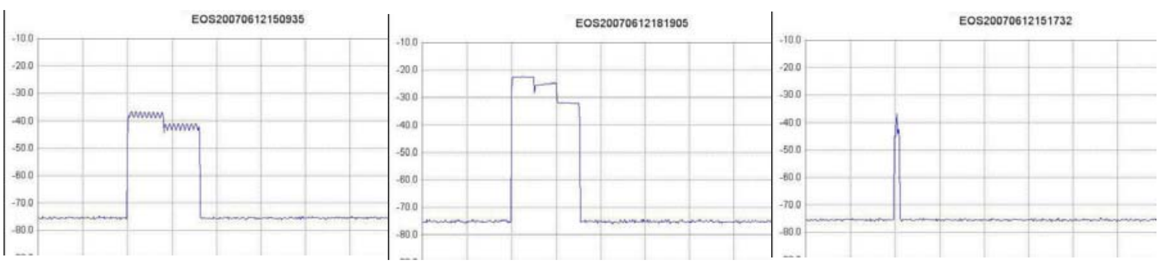
Measurements

Measurement methodology is described in more detail in Appendices A, B, and F. In summary, a spectrum analyzer was employed as a filtered, triggered oscilloscope to capture received radar pulses. The results are samples of the strongest received radar pulses displayed as a function of time, presented visually in Appendix C and quantitatively in electronic form. This approach creates in effect, a “picture” of each pulse.

In Figure 1, pulse images A, B, and C, illustrate the three primary pulse types obtained in the measurements. These figures show time horizontally, and signal strength vertically. Pulse A shows a “doublet” pulse. The radar emits two pulses in rapid succession in some directions of the compass. The pulse has two distinct segments of equal width, from which the name “doublet” derives. When the measurement site is in the region of the Cape above which doublets are transmitted, the strongest pulses received will be primarily doublets like Pulse A.

Pulse B shows a “triplet” pulse. This is a set of three pulses transmitted in rapid succession. Triplets occur at azimuths where doublets do not. While our instrumentation is sensitive enough to pick up doublets and triplets at any single location, the strongest pulses received at that location will usually be the pulses transmitted directly overhead. Since our objective was to collect only the strongest pulses received, each site’s collected pulses will favor one or the other—doublets or triplets—as the strongest pulses. Note that the radar is designed to transmit the doublet or the triplet for about the same length of time, as the full width of the doublet in Pulse A is about the same as the full width of the triplet in Pulse B, or approximately 15-16 milliseconds.

Figure 1
Pulses: Doublet, Triplet, Narrow



Vertical axis: dB relative to one milliwatt @ 10 dB per division
Horizontal axis: Time = 10 milliseconds per division

Pulse A	Pulse B	Pulse C
Doublet	Triplet	Narrow

Doublet and triplet pulses are used in the Long Range Surveillance (“LRS”) work of the radar. LRS is used to find distant targets. The pulses are wide, which means they are longer in duration than another pulse employed by the radar, because they have far to go and the radar can use the substantial pulse width to get a better reflection to measure off a distant target. This is a way of increasing the received power of a distant radar echo without increasing the power of the transmitted pulse.

The radar also has a Short Range Surveillance (“SRS”) mode. In this mode, the radar is looking at a shorter distance and does not need such wide pulses for reasons that need not be belabored here. Pulse C is a narrow SRS pulse. The radar interleaves SRS pulses with LRS pulses, so both can be seen from any measurement site. In addition to its surveillance mission, the radar is capable of tracking a target that it acquires during surveillance. Since the surveillance "fence" is at the lowest angle above the horizon at which the radar operates and therefore most proximate to the ground-level environment, the highest-level pulses recorded were SRS and LRS pulses.

To ensure the instrumentation accurately captured the highest pulse power levels at each measurement location, care was taken to ensure there was plenty of headroom in the measurement apparatus. Headroom is a term that refers to having the ability to handle signals that are stronger than anticipated. This avoids a condition called "clipping" in which the peak levels of unanticipated strong signals are cut off, producing understated results. As described in the methodology in Appendix A, the instrumentation was set up at each site to handle unanticipated pulses at least one to two orders of magnitude greater than the highest pulses observed during site set-up.

Presentation of Results

Pulse "Pictures"

The measurements are presented in several ways. First, for Appendix C the collected pulses were sorted in order of signal strength, and the twelve highest level pulses captured at each site are shown. These are presented pictorially in Appendix C. The radar employs doublets at the last 12 degrees or so of each of the two radar faces, and triplets across the remaining 96 degrees centered on each face, so each site is dominated by either doublets or triplets. Short range pulses are emitted across the entire width of each radar face and are likely to appear among the strongest pulses at each site. Each collection of 12 highest pulses from a site contains a mixture of various pulse types.

Pulse Data

Second, the data for each pulse were collated from the raw data files into more computer-readable form. At some sites there are more pulses recorded than at others. This is the result of our observing fewer pulses above the threshold at some sites compared to others. This information is simply the numerical data for each pulse, from which images of the pulses can be created. The raw data are in units of dBm as measured by the instrument.

The term “dBm” is a unit of *power* measured by the spectrum analyzer in the test vehicle. It appears in certain columns in Tables 2, 3, & 4. It represents “decibels with respect to one milliwatt.” Negative dBm numbers represent power levels that are less than 1 milliwatt, while positive numbers are greater than 1 milliwatt. All the collected data are negative dBm values.

The power measurements in dBm are specific to the test instrumentation and must be translated to a unit of measure employed in environmental exposure analysis. This enables one to compare the data from this study with the data from the 2004 and prior PAVE PAWS studies. That measure is in terms of *power density*. Power density is the measure of the amount of *power per unit area*. This conversion is explained in detail in Appendix B. Essentially, we combine the measured power level in dBm with the known size (area) of the calibrated test antenna receiving the radar signals. From this we develop an environmental power density figure for each peak pulse power measurement. Power density is expressed in terms of power per unit area. In this study, we employ a power unit expressed in dB with respect to one microwatt per square centimeter. This is abbreviated as dBμW/cm^2.

<u>Maximum Pulse Level at Each Site</u>

Third, the measurements were screened to identify the single most powerful pulse received at each site. These selected samples are employed in the maximum peak pulse power analysis in Tables 2 and 3 and Figure 2 (as well as the three Figures in Appendix D), discussed further below.

Results

The highest-level pulse captured at each site in 2007 (the maximum recorded peak pulse power) was identified, and the values tabulated for comparison. Table 2 lists the maximum peak pulse power measured at each site, sorted from top to bottom in order from highest to lowest power. The index sites are sorted independently of the comparison sites. The two sets are side by side in the table for ease of reading. No association between sites in the same row is implied.

Table 2- Highest Peak Pulse Power Data[7]

Index Sites			Comparison Sites		
Value	Highest Measured Peak Pulse Power	Converted to Equivalent Power Density		Highest Measured Peak Pulse Power	Converted to Equivalent Power Density
Unit of Measure	dBm	dBμW/cm^2		dBm	dBμW/cm^2
Site no.			Site no.		
BSL04	-21	-12.8	PP09	-12.3	-4.1
BSL15	-31.6	-23.4	PP40	-13.1	-4.9
BSL05	-35.6	-27.4	PP16	-15.2	-7
BSL01	-36.6	-28.4	PP21	-21.6	-13.4
BSL03	-37.2	-29	PP19	-27.2	-19
BSL11	-41.8	-33.6	PP18	-31.6	-23.4
BSL07	-42.3	-34.1	PP17	-32.3	-24.1
BSL12	-49.9	-41.7	PP34	-43.5	-35.3
BSL17	-50	-41.8	PP07	-46.3	-38.1
BSL14	-53.1	-44.9	PP51	-47.9	-39.7
BSL02	-53.7	-45.5	PP50	-50	-41.8
BSL06	-54.1	-45.9	PP10	-52.8	-44.6
BSL10	-55	-46.8	PP42	-63.7	-55.5
BSL09	-59.6	-51.4	PP52	-68	-59.8
BSL08	-59.9	-51.7			
BSL13	-63.9	-55.7			
BSL16	-71.3	-63.1			

Employing the peak data from Table 2, Table 3 tabulates the peak data with corresponding average data and other information for each site. In the top segment of Table 3, the peak pulse power at all index sites is presented in order of site number. In the middle segment of Table 3, the peak data for the comparison sites are also presented. These two sections of Table are employed to compare peak data with the map-based average data. The bottom segment of Table 3 repeats the peak data for the comparison sites, but this time the data are associated with 2004 field-measured data for all 2004 sites incorporated into the 2007 comparison site set.

[7] While not an objective of the present study, it may be helpful to place these measured values in context. The IEEE C95.1 limit for *average exposure* of the general population to emissions in the PAVE PAWS radar spectrum is about +25 dBμW/cm^2 over a 30-minute period. The highest *peak pulse power level* measured was -4.1 dBμW/cm^2, which is 29 dB lower than the current 30-minute average safety limit.

The third column of Table 3 presents the peak data in original measured units of dBm. The fourth column of Table 3 contains the translations of peak pulse power measurements to power density (dBµW/cm^2). This enables a direct comparison of the 2007 peak pulse power data with the 2004 average power data, in units of power density. To obtain estimated average data for comparison in the fifth column (Average), predicted average power levels were derived from the 2004 radar power density map (Exhibit E) or from 2004 measured data.

The peak-to-average ratio is presented in the Pk/Avg column of Table 3. The Radar Zone column is discussed in the measurement protocol (Appendix F) and deals with whether the subject site is in the region in which the sidelobes of both radar faces tend to overlap (Zone 1) or in a region in front of one face but behind the other (Zones 2 & 3). The Path characteristic is a simple indication of the role of terrain in the signal path. The number in the Path column represents the number of points of terrain diffraction between source and destination. This represents, simply stated, the number of hills over which the radar signal must bend to get to its target. Zero indicates that a nominal line of sight is obtained to the radar, assuming bare earth with no vegetation and structures. Each additional point of diffraction is responsible for 6-12 dB of attenuation above the raw path loss due to distance. Highly diffracted locations will have substantially lower signal levels than clear path locations, given the same distance and azimuth to the radar.

Table 3- Peak and Average Data

Value		Highest Measured Peak Pulse Power	Converted to Equivalent Power Density	Average Power Density (see column 1 for source)	Peak-to-average ratio	Distance	Radar “zone”	Path*
Units		dBm	dBuW/cm^2	dBuW/cm^2	dB	km		
	Site							
Index Sites	BSL01	-36.6	-28.4	-21.8	-6.6	5.35	1	1
	BSL02	-53.7	-45.5	-72.8	27.3	19.7	2	3
Average values are from PP 2004 Broadcast Signal Lab map matrix.	BSL03	-37.2	-29	-44.8	15.8	6.64	1	0
	BSL04	-21	-12.8	-22.8	10	3.5	3	0
	BSL05	-35.6	-27.4	-27.8	0.4	4.24	1	0
	BSL06	-54.1	-45.9	-43.8	-2.1	15	1	0
	BSL07	-42.3	-34.1	-43.8	9.7	9.07	2	0
	BSL08	-59.9	-51.7	-56.8	5.1	23.3	2	2
	BSL09	-59.6	-51.4	-52.8	1.4	32.5	1	0
	BSL10	-55	-46.8	-63.8	17	37.2	1	1
	BSL11	-41.8	-33.6	-40.8	7.2	9.1	1	0
	BSL12	-49.9	-41.7	-68.8	27.1	29.5	1	1
	BSL13	-63.9	-55.7	-82.8	27.1	34.3	1	2
	BSL14	-53.1	-44.9	-40.8	-4.1	11.1	1	1
	BSL15	-31.6	-23.4	-48.8	25.4	6.86	1	3
	BSL16	-71.3	-63.1	-62.8	-0.3	29.6	1	1
	BSL17	-50	-41.8	-63.8	22	32	1	1
Comparison Sites	PP07	-46.3	-38.1	-45.8	7.7	38	1	0
	PP09	-12.3	-4.1	-34.8	30.7	29.8	1	0
Average values are from PP 2004 Broadcast Signal Lab map matrix.	PP10	-52.8	-44.6	-39.8	-4.8	24.8	1	0
	PP16	-15.2	-7	-22.8	15.8	4.52	1	0
	PP17	-32.3	-24.1	-35.8	11.7	5.96	1	0
	PP18	-31.6	-23.4	-26.8	3.4	4.43	1	1
	PP19	-27.2	-19	-30.8	11.8	3.94	1	0
	PP21	-21.6	-13.4	-19.8	6.4	4.17	1	0
	PP34	-43.5	-35.3	-38.8	3.5	8.8	2	0
	PP40	-13.1	-4.9	-29.8	24.9	1.53	3	0
	PP42	-63.7	-55.5	-46.8	-8.7	9.14	1	4
	PP50	-50	-41.8	-62.8	21	20.9	1	1
	PP51	-47.9	-39.7	-42.7	3	21.5	1	0
	PP52	-68	-59.8	-62.7	2.9	27.5	1	1
Comparison Sites	PP07	-46.3	-38.1	-48.8	10.7	38	1	0
	PP09	-12.3	-4.1	-24.2	20.1	29.8	1	0
	PP10	-52.8	-44.6	-55.9	11.3	24.8	1	0
	PP16	-15.2	-7	-31.1	24.1	4.52	1	0
	PP17	-32.3	-24.1	-49.8	25.7	5.96	1	0
	PP18	-31.6	-23.4	-38.8	15.4	4.43	1	1
Average values are from PP 2004 actual measurements (sites 51 & 52 are not part of 2004 measurement survey and are excepted from this section)	PP19	-27.2	-19	-36.5	17.5	3.94	1	0
	PP21	-21.6	-13.4	-25.9	12.5	4.17	1	0
	PP34	-43.5	-35.3	-46	10.7	8.8	2	0
	PP40	-13.1	-4.9	-24	19.1	1.53	3	0
	PP42	-63.7	-55.5	-65.9	10.4	9.14	1	4
	PP50	-50	-41.8	-66.5	24.7	20.9	1	1
	PP51	-47.9	-39.7	N/A				
	PP52	-68	-59.8	N/A				

Results Discussion

Numerical Comparison

To compare the set of peak pulse power measurements (in dBm) for the 17 index sites with those of the 14 comparison sites, the results are presented statistically in Table 4. As anticipated in the discussion of site characteristics in Table 1, there is a greater average level at the comparison sites than the index sites. This result supports the premise that the physical characteristics of individual sites are primary determinants of peak pulse power received at each site. In other words, the measured emissions of the PAVE PAWS radar and the propagation of its signals into the environment are consistent between the index sites and comparison sites.

Table 4
Distributions of Highest Peak Pulse Power Measurements (dBm) of both Sets of Sites

Statistic	Index	Comparison
average	-48.04	-37.54
median	-50	-37.9
Std Dev	12.97	18.35
min	-71.3	-68
max	-21	-12.3

Table 4 also shows that the distribution of the highest peak levels at each set of sites is similar for index and comparison site sets, with each standard deviation being between 10 and 20 dB. The distribution difference (in standard deviation) between peak pulse power measurements of the index site set (13 dB) and comparison site sets (18 dB) is 5 dB. In mild contrast, the difference in distributions of the individual site characteristics of Table 1 suggested the spread of the results at the index and comparison sites might be closer, because Table 1 showed a 1-2 dB spread in the standard deviations of the elevation, distance, and average power characteristics of the two sets of sites. While this difference is apparent, if it is not simply an artifact of the small data set sizes, it is still reassuring because the index site data are not out of line with the comparison site data.

The comparison sites exhibited the greater standard deviation (18 dB) in measured peak levels. The distribution of the values among the index sites was a less variable 13 dB standard deviation.

This suggests that our comparison sites at Shawme Crowell State Park (PP40), Cardinal Road Circle (PP16) and Scargo Hill (PP09), where substantially higher measurements were obtained than at any index locations, may have skewed the comparison site distribution to a broader standard deviation. This is not a flaw. It confirms that the range of possible peak pulse power levels on the upper Cape includes levels that are substantially stronger than observed at the index sites.

Overall, the statistics of the index and comparison site peak pulse power measurements indicate the index site peak pulse power measurements were slightly more homogenous than the comparison sites. The index sites as a set were lower in level and less diverse in level than the comparison sites.

Graphical Comparison

Figure 2 represents the measurement data visually, allowing the eye to corroborate what Table 4 says statistically. Plots were generated to illustrate the relationships between distance to the radar and signal level. The two sets of the 2007 maximum peak level data, from index and comparison sites, are compared in Figure 2. The peak data and distances are taken from Table 3. Figure 2 is reproduced in Appendix D along with additional figures comparing peak and average data.

Figure 2 - Index and Comparison Sites Peaks

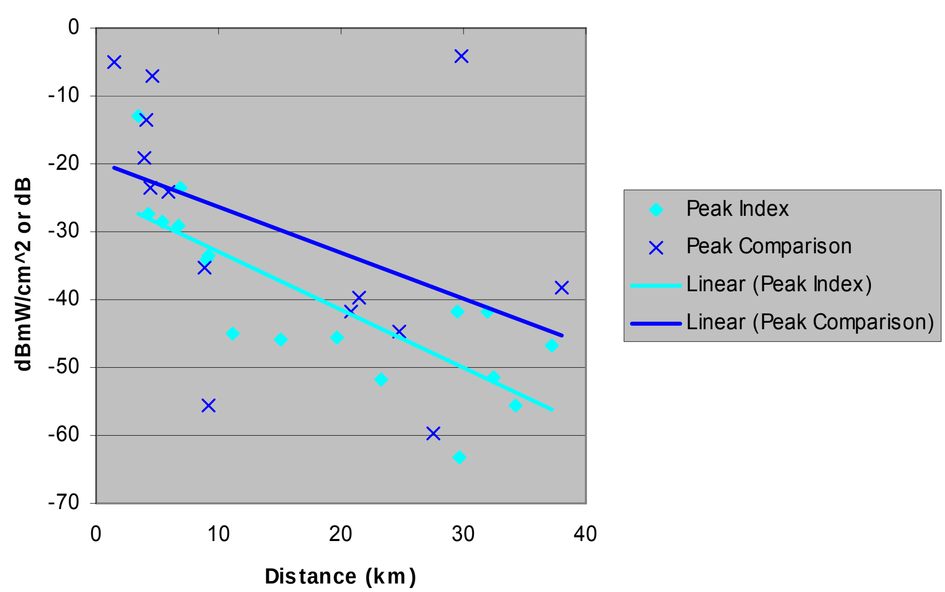


Figure 2 illustrates the similar nature of the two sets of data. The index sites, as a set, show a typical peak level slightly lower than, but otherwise similar to the comparison sites. This is consistent with the observations about higher comparison site levels discussed with Tables 1 and 4 above.

Figure 2 has linear trend lines for the index and comparison site data sets. These lines show both sets tapering off in signal strength with distance in a similar fashion. The general slope of these lines is consistent with radio propagation over distance in an environment with terrain and land cover. The index site trend line is about 8 to 10 dB lower than that of the comparison site set, which is consistent with the fact that the index site data set has proportionally more locations that have terrain-obstructed paths than the comparison site set, and several comparison sites have the highest recorded levels.

Summary of Findings on the Results

Overall, our experience in taking the measurements conforms with our experience and understanding of radio propagation in general and the PAVE PAWS radar in particular—namely, the index sites appear to be exposed to the same range of characteristics in the radar pulses as are the comparison sites. Other than the subtle distinction between the two sets due to signal path characteristics, there is no obvious distinction that would set the index sites apart from the comparison sites, both in general and on a site by site basis.

Similarly, our 2004 observations about stronger emissions being received at high elevation sites with good lines of sight to the radar are corroborated in this 2007 survey employing peak power density analysis. The characteristic of a site being a high elevation location with an open path to the radar is a key element in obtaining the strongest received signals from the radar. The 2007 peak data and the 2004 average each data support this observation because for a given distance, the sites with the highest signal levels (peak or average) were the sites with the best line of sight to the radar.

Peak-to-Average Ratios and the Utility of the 2004 Study Average Power Density Map

The distributions of the 2007 peak-to-average ratio data (discussed further in Appendix D), the 2007 peak data, and the 2004 average data support a conclusion that peak-pulse and average power densities generally track the variability in propagation resulting from terrain, distance, and land cover. With more statistical analysis one may be able to more rigorously determine a means for estimating peak pulse power received at a site based on the 2004 average power map. Our initial conclusion is that a typical peak-pulse-power-to-average-power ratio is in the vicinity of 15 dB, with an uncertainty that could be addressed to a high degree of certainty by using a conservative ratio of 30 dB. That is, we do not expect that the actual peak pulse power levels in the environment would be more than 30 dB above the average emissions of the radar at the same location, and that it is more likely to be near a figure of 15 dB. Hence, one may be able to employ the average power density map and its underlying data from the 2004 PAVE PAWS study to estimate the likely range of peak pulse emissions received at a given site.

No Anomalies in the Recorded Data

Only bona fide radar pulses were captured in the study, with no unusual characteristics observed in the shape or intensity of peak pulse emissions received at any site. By serendipity, we did occasionally capture signals from handheld remote transmitters, such as when a passerby was observed remotely unlocking her car within a hundred yards of a test site (see Appendix C, site BSL03). Many automobile and similar low power remote transmitters operate on a frequency in the PAVE PAWS radar band. On the rare occasion that such signals were observed, they were lower in level than the captured radar pulse occurring at the same time. Their presence did not interfere with collection of peak pulse power levels of the radar.

Conclusion

The 2007 survey of PAVE PAWS peak pulse emissions was conducted using the 2004 study as a basis, both for methodology and for potential comparison. The instrumentation used in 2007 included gear employed in 2004, but more simply configured for the 2007 objective. 31 sites were surveyed for sufficient lengths of time to capture a quantity of the highest pulse peaks arriving at the sites. The collected data were tabulated and prepared graphically. Average data from the 2004 study were incorporated in this report to enable further comparisons and analysis. Tabular data on all pulses sampled are submitted in electronic form.

Based on our experience in radio frequency engineering, there is no obvious difference in the peak pulse powers received at the index sites relative to those received at the comparison sites. The measured peak pulse power levels at the index sites were of magnitudes individually, and as a set, that were very similar to those measured at the comparison sites. The index sites do not have exceptional characteristics with respect to the general propagation of energy from the PAVE PAWS radar. The peak pulse power levels obtained at the index sites fall within the normal range of emissions expected from the PAVE PAWS radar at publicly accessible locations on Cape Cod.

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